

CHEMSYSTEMS **SPECIAL REPORT**

Evolving Propylene Sources Solution to Supply Shortages?

January 2012



44 South Broadway, White Plains, New York 10601, USA
Tel: +1 914 609 0300 Fax: +1 914 609 0399

Copyright© by Nexant, Inc. 2012

This report was prepared by Nexant, Inc. ("NEXANT") and is part of the ChemSystems Topical Report Program. Except where specifically stated otherwise in this Report, the information contained herein is prepared on the basis of information that is publicly available, and contains no confidential third party technical information to the best knowledge of NEXANT. Aforesaid information has not been independently verified or otherwise examined to determine its accuracy, completeness or financial feasibility.

Neither NEXANT, Subscriber nor any person acting on behalf of either assumes any liabilities with respect to the use of or for damages resulting from the use of any information contained in this Report. NEXANT does not represent or warrant that any assumed conditions will come to pass.

The Report is submitted on the understanding that the Subscriber will maintain the contents confidential except for the Subscriber's internal use. The Report should not be reproduced, distributed or used without first obtaining prior written consent by NEXANT. Each Subscriber agrees to use reasonable effort to protect the confidential nature of the Report.

Contents

Section	Page
1 Executive Summary	1-1
1.1 INTRODUCTION	1-1
1.2 STUDY OBJECTIVES.....	1-2
1.3 TECHNOLOGY	1-2
1.4 ECONOMICS	1-5
1.4.1 Byproduct Propylene Economics.....	1-6
1.4.2 On-Purpose Propylene Economics	1-8
1.4.3 Delivered Propylene Economics.....	1-11
1.5 CRUDE OIL SENSITIVITY	1-14
1.5.1 United States	1-14
1.6 MARKET ANALYSIS.....	1-15
1.6.1 Global Consumption	1-15
1.6.2 Global Capacity	1-17
1.6.3 Global Supply, Demand, and Trade.....	1-18
1.6.4 North American Propylene Shortage	1-19
2 Conventional Propylene Technology.....	2-1
2.1 OVERVIEW	2-1
2.2 STEAM CRACKING	2-2
2.2.1 Process Description.....	2-5
2.3 PROPYLENE FROM CATALYTIC CRACKING.....	2-13
2.3.1 Recovery from Refinery Streams.....	2-13
2.3.2 Enhanced (High Severity) FCC	2-14
2.3.3 Resid to Propylene FCC (RFCC).....	2-41
2.3.4 Advanced Cracking of Refinery Streams	2-48
3 Alternative and On-Purpose Technologies.....	3-1
3.1 OVERVIEW	3-1
3.2 PROPANE DEHYDROGENATION (PDH)	3-1
3.2.1 Process Design	3-1
3.3 OLEFIN METATHESIS	3-19

3.3.1	Chemistry	3-20
3.3.2	Process Design	3-21
3.3.3	Lummus Olefin Conversion Technology (OCT)	3-22
3.3.4	Mitsui Metathesis Technology	3-26
3.3.5	UOP Metathesis Technology	3-26
4	Alternative Feedstocks	4-1
4.1	OVERVIEW	4-1
4.2	SELECTIVE OLEFIN CRACKING	4-1
4.2.1	Methanol to Olefins (MTO)/Methanol to Propylene (MTP)	4-1
4.3	BIO-PROPYLENE	4-8
4.3.1	Biomass to Ethanol	4-8
4.3.2	Ethanol to Propylene	4-37
4.3.3	Ethylene Dimerization to Butene	4-38
4.3.4	Fermentation to Propanol Followed by Dehydration	4-41
4.3.5	Biomass Gasification	4-48
5	Economics	5-1
5.1	ECONOMIC BASES	5-1
5.1.1	Cost of Production Definition and Basis	5-1
5.1.2	Nexant's Pricing Basis	5-6
5.2	BYPRODUCT PROPYLENE ECONOMICS	5-10
5.2.1	United States	5-10
5.2.2	Western Europe	5-12
5.2.3	Coastal China	5-14
5.3	ON-PURPOSE PROPYLENE ECONOMICS	5-16
5.3.1	United States	5-17
5.3.2	Western Europe	5-21
5.3.3	Middle East	5-24
5.3.4	Coastal China	5-26
5.4	REGIONAL COMPETITIVENESS	5-28
5.4.1	United States	5-28
5.4.2	Western Europe	5-32

5.4.3	Coastal China	5-35
5.5	CRUDE OIL SENSITIVITY	5-37
5.5.1	United States	5-37
5.5.2	Western Europe.....	5-39
5.5.3	Middle East	5-41
5.5.4	Coastal China	5-42
6	Propylene Market Section	6-1
6.1	GLOBAL OVERVIEW	6-1
6.1.1	Introduction.....	6-1
6.2	GLOBAL MARKET	6-2
6.2.1	Consumption	6-2
6.2.2	Capacity	6-4
6.2.3	Supply, Demand, and Trade.....	6-5
6.3	NORTH AMERICA	6-6
6.3.1	Consumption	6-6
6.3.2	Capacity	6-8
6.3.3	Supply, Demand, and Trade.....	6-14
6.4	ASIA PACIFIC	6-16
6.4.1	Consumption.....	6-16
6.4.2	Capacity	6-18
6.4.3	Supply, Demand, and Trade.....	6-24
6.5	WESTERN EUROPE	6-26
6.5.1	Consumption	6-26
6.5.2	Capacity	6-28
6.5.3	Supply, Demand, and Trade.....	6-33
6.6	MIDDLE EAST	6-34
6.6.1	Consumption	6-34
6.6.2	Capacity	6-35
6.6.3	Supply, Demand, and Trade.....	6-37
6.7	REST OF WORLD	6-38
6.7.1	Consumption	6-38

6.7.2	Capacity	6-39
6.7.3	Supply, Demand, and Trade.....	6-42
6.8	NORTH AMERICAN PROPYLENE SHORTAGE	6-43

Appendix	Page
A	
Cost of Production Estimate	A-1

Figure	Page
1.1 Ethylene Cost of Production with Enhanced Propylene Production	1-7
1.2 Ethylene Cost of Production with Enhanced Propylene Production	1-7
1.3 On-purpose Propylene Cost of Production	1-10
1.4 On-purpose Propylene Cost of Production	1-10
1.5 Delivered Costs of Propylene, United States	1-12
1.6 Delivered Costs of Propylene, United States	1-13
1.7 Sensitivity of Propylene Cost of Production to High Oil Scenario, U.S.	1-15
1.8 Regional Combined Propylene Capacity	1-17
1.9 Global Propylene Supply and Demand.....	1-18
1.10 Historical U.S. Propylene Production per Ton of Ethylene.....	1-19
1.11 Ratio of Propylene to Ethylene Prices	1-20
1.12 Global Propylene Price Forecast.....	1-21
1.13 U.S. Propylene Derivative Demand Growth Compared to U.S. GDP.....	1-22
1.14 U.S. Propylene Derivative Demand Growth compared to U.S. GDP.....	1-22
1.15 U.S. Propylene Trade Data	1-23
1.16 U.S. Exports of Propylene Derivatives	1-24
1.17 U.S. Production of Refinery Propylene and U.S. Gasoline Production.....	1-24
2.1 Ethylene Plant: Cracking of NGL, Cracking and Compression Section	2-11
2.2 Ethylene Plant: Cracking of NGL, Fractionation Section	2-12
2.3 Refinery Propylene Upgrading Process Flow Diagram.....	2-15
2.4 Typical UOP PetroFCC™ Complex.....	2-20
2.5 Typical UOP RxPro™ Complex	2-24
2.6 Schematic of the Down-Flow Reactor	2-29
2.7 MAXOFIN FCC Unit	2-30
2.8 SUPERFLEX™ Reactor System	2-33
2.9 CC Simplified Process Flow Diagram	2-38
2.10 UOP RFCC Reactor-Regenerator	2-42
2.11 KBR RFCC Converter	2-44
2.12 RTP Process Scheme	2-46
2.13 R2R Technology	2-47

2.14 R2R Process Unit.....	2-48
2.15 ACO™ Flow Scheme - Reactor Section	2-50
2.16 Typical ACO™ Flow Scheme – Compression/Recovery Sections	2-51
3.1 Oleflex™ Propane Dehydrogenation Simplified Flow Diagram.....	3-4
3.2 Oleflex™ Catalyst Regeneration Simplified Flow Diagram	3-7
3.3 Lummus CATOFIN® Process	3-12
3.4 Linde PDH Reaction and Regeneration Section	3-13
3.5 Snamprogetti/Yarsintez FBD Propane Dehydrogenation Simplified Flow Diagram.....	3-15
3.6 Uhde STAR Propane Dehydrogenation Simplified Flow Diagram.....	3-18
3.7 Simplified Flow Diagram for Propylene via Metathesis (Lummus)	3-25
3.8 UOP Light Olefins Production Flow Diagram	3-27
4.1 UOP/HYDRO MTO Process: Simplified Flow Diagram.....	4-3
4.2 Wet Milling versus Dry Milling	4-9
4.3 Corn Receiving Storage and Milling Whole Kernel Milling.....	4-11
4.4 Milling and Hydrolysis Whole Kernel Milling.....	4-12
4.5 Saccharification Whole Kernel Milling	4-13
4.6 Fermentation Whole Kernel Milling.....	4-14
4.7 Beer Still Dry Corn Milling	4-15
4.8 Rectifier and Dehydration Corn Dry Milling.....	4-16
4.9 DDGS Drying Whole Kernel Milling.....	4-17
4.10 Ethanol Pasteurization and Vent Recovery Whole Kernel Milling	4-18
4.11 Block Flow Diagram of Ethanol Production from Sugarcane	4-29
4.12 Material Balance of Ethanol Production from Sugarcane and Bagasse	4-30
4.13 Conceptual Structure of Cellulose in Plants	4-32
4.14 NREL Lignocellulosic Biomass to Ethanol Process.....	4-33
4.15 Butene-1 Via Ethylene Dimerization (Axens Alhabutol Process).....	4-40
4.16 Solventogenesis Metabolic Pathways	4-43
4.17 Fermentation Propanol Pathway Genome Sources and Augmentations.....	4-44
4.18 Plastid Augmentation.....	4-45
4.19 Schematic Flowsheet of Batch Gevo Patent Application US/2009 0246842 A1 Fermentation Propanol Production Process	4-46

4.20	Block Flow Diagram: Fermentation Bio-Propanol Route to Propylene	4-46
4.21	Process Schematic – CHOREN Syngas Production from Biomass.....	4-50
4.22	PulseEnhanced™ Steam Reformer.....	4-54
4.23	Pulsed Heater – Flue Gas Biomass Gasification Heat Transfer	4-54
4.24	Selected Methanol Reformer Options.....	4-56
5.1	Production Cost Elements.....	5-2
5.2	Historical Crude Oil Price.....	5-8
5.3	Real Price of Crude Oil.....	5-8
5.4	Crude Oil Price Scenarios.....	5-9
5.5	Ethylene Cost of Production with Enhanced Propylene Production (U.S. dollars per metric ton, USGC., 2011)	5-11
5.6	Ethylene Cost of Production with Enhanced Propylene Production	5-12
5.7	Ethylene Cost of Production with Enhanced Propylene Production	5-13
5.8	Ethylene Cost of Production with Enhanced Propylene Production	5-14
5.9	Ethylene Cost of Production with Enhanced Propylene Production	5-15
5.10	Ethylene Cost of Production with Enhanced Propylene Production	5-16
5.11	On-purpose Propylene Cost of Production	5-18
5.12	On-purpose Propylene Cost of Production	5-20
5.13	On-purpose Propylene Cost of Production	5-22
5.14	On-purpose Propylene Cost of Production	5-23
5.15	On-purpose Propylene Cost of Production	5-24
5.16	On-purpose Propylene Cost of Production	5-25
5.17	On-purpose Propylene Cost of Production	5-27
5.18	On-purpose Propylene Cost of Production	5-28
5.19	Delivered Costs of Propylene, United States.....	5-30
5.20	Delivered Costs of Propylene, United States.....	5-31
5.21	Delivered Costs of Propylene, Western Europe	5-33
5.22	Delivered Costs of Propylene, Western Europe	5-34
5.23	Delivered Costs of Propylene, China.....	5-36
5.24	Delivered Costs of Propylene, China.....	5-37
5.25	Sensitivity of Propylene Cost of Production to High Oil Scenario, U.S.	5-39

5.26 Sensitivity of Propylene Cost of Production to High Oil Scenario, Western Europe	5-40
5.27 Sensitivity of Propylene Cost of Production to High Oil Scenario, Middle East	5-41
5.28 Sensitivity of Propylene Cost of Production to High Oil Scenario, China	5-43
6.1 Global Consumption of Propylene by End-Use, 2011.....	6-3
6.2 Regional Combined Propylene Capacity	6-5
6.3 Global Propylene Supply and Demand.....	6-6
6.4 North American Propylene Consumption, 2011.....	6-8
6.5 North American Propylene Supply and Demand.....	6-15
6.6 Asia Pacific Propylene Consumption, 2011	6-17
6.7 Asia Pacific Propylene Supply, Demand, and Trade.....	6-25
6.8 West European Propylene Consumption, 2011	6-27
6.9 Western Europe Supply Demand and Trade.....	6-34
6.10 Middle East Propylene Consumption, 2011	6-35
6.11 Middle East Supply, Demand, and Trade	6-38
6.12 Propylene Consumption in ROW, 2011	6-39
6.13 ROW Supply Demand and Trade	6-42
6.14 Historical U.S. Propylene Production per Ton of Ethylene.....	6-44
6.15 Ratio of Propylene to Ethylene Prices	6-45
6.16 Global Propylene Price Forecast.....	6-46
6.17 U.S. Propylene Derivative Demand Growth compared to U.S. GDP.....	6-47
6.18 U.S. Propylene Derivative Demand Growth compared to U.S. GDP.....	6-48
6.19 U.S. Propylene Trade Data	6-49
6.20 U.S. Exports of Propylene Derivatives	6-49
6.21 U.S. Production of Refinery Propylene and U.S. Gasoline Production.....	6-50

Table	Page
1.1 Propane Dehydrogenation Process Characteristics.....	1-3
1.2 Global Propylene Consumption by End-Use.....	1-16
1.3 Global Propylene Supply and Demand.....	1-18
2.1 Propylene Yield from Representative Cracker Feedstocks	2-4
2.2 Impact of Feedstock and Flexibility on Investment Cost	2-5
2.3 Propylene Product Specifications	2-13
2.4 FCC Product Yield Comparisons Across Operating Modes.....	2-18
2.5 High Severity Fluid Cracking Technologies.....	2-19
2.6 Yield Patterns – Traditional FCC versus PetroFCC™	2-23
2.7 Typical Olefin Yields for the I-FCC™ Process.....	2-26
2.8 MAXOFIN™ FCC Unit Operating Modes	2-31
2.9 SUPERFLEX™ Operating Modes and Feedstocks.....	2-32
2.10 DCC Product Slate and Olefin Yield	2-35
2.11 DCC Type I and FCC Design Operating Conditions.....	2-36
2.12 Yields: CPP versus Steam Cracking	2-40
3.1 Propane Dehydrogenation Process Characteristics.....	3-1
3.2 Propane Dehydrogenation Material Balance	3-2
3.3 Star Dehydrogenation Process Conditions.....	3-17
3.4 Metathesis Process Characteristics	3-21
3.5 Representative C ₄ Stream Compositions	3-22
4.1 Component Yield from UOP/HYDRO MTO Process (SAPO-34 Fluid-Bed Steady State Operation)	4-4
4.2 UOP/HYDRO MTO Flexibility.....	4-4
4.3 Typical Corn Analysis	4-10
4.4 Safe Corn Storage Life.....	4-19
4.5 Major Unit Operations of NREL Bioethanol Process.....	4-32
4.6 Fermentation Propanol Patent Matrix.....	4-41
5.1 Shipping Costs	5-6
5.2 Historical Crude Oil Prices, 1990-2011 YTD.....	5-7
5.3 Ethylene Cost of Production with Enhanced Propylene Production	5-11

5.4	Ethylene Cost of Production with Enhanced Propylene Production	5-11
5.5	Ethylene Cost of Production with Enhanced Propylene Production	5-12
5.6	Ethylene Cost of Production with Enhanced Propylene Production	5-13
5.7	Ethylene Cost of Production with Enhanced Propylene Production	5-14
5.8	Ethylene Cost of Production with Enhanced Propylene Production	5-15
5.9	On-purpose Propylene Cost of Production	5-18
5.10	On-purpose Propylene Cost of Production	5-19
5.11	On-purpose Propylene Cost of Production	5-21
5.12	On-purpose Propylene Cost of Production	5-23
5.13	On-purpose Propylene Cost of Production	5-24
5.14	On-purpose Propylene Cost of Production	5-25
5.15	On-purpose Propylene Cost of Production	5-26
5.16	On-purpose Propylene Cost of Production	5-27
5.17	Delivered Costs of Propylene, United States	5-29
5.18	Delivered Costs of Propylene, United States	5-31
5.19	Delivered Costs of Propylene, Western Europe	5-32
5.20	Delivered Costs of Propylene, Western Europe	5-34
5.21	Delivered Costs of Propylene, China	5-35
5.22	Delivered Costs of Propylene, China	5-36
5.23	Sensitivity of Propylene Cost of Production to High Oil Scenario, U.S.	5-38
5.24	Sensitivity of Propylene Cost of Production to High Oil Scenario, Western Europe	5-40
5.25	Sensitivity of Propylene Cost of Production to High Oil Scenario, Middle East	5-41
5.26	Sensitivity of Propylene Cost of Production to High Oil Scenario, China	5-42
6.1	Global Propylene Consumption by End-Use	6-3
6.2	Regional Propylene Consumption	6-4
6.3	Global Propylene Supply and Demand	6-6
6.4	North American Polymer/Chemical Grade Propylene Consumption	6-7
6.5	North American Refinery Grade Propylene Consumption	6-7
6.6	Polymer/Chemical Grade Propylene Capacity in North America	6-10
6.7	Refinery Grade Propylene in North America	6-13
6.8	North America Propylene Supply/Demand and Trade	6-15

6.9 Asia Pacific Polymer/Chemical Grade Propylene Consumption.....	6-16
6.10 Asia Pacific Refinery Grade Propylene Consumption.....	6-16
6.11 Polymer/Chemical Grade Propylene in Asia Pacific	6-19
6.12 Refinery Grade Propylene Capacity in Asia Pacific.....	6-24
6.13 Asia Pacific Propylene Supply, Demand and Trade.....	6-25
6.14 Western Europe Polymer/Chemical Grade Propylene Consumption	6-26
6.15 Western Europe Refinery Grade Propylene Consumption	6-26
6.16 Polymer/Chemical Grade Propylene Capacity in Western Europe	6-29
6.17 Refinery Grade Propylene Capacity in Western Europe	6-32
6.18 Western Europe Combined Propylene Supply/Demand and Trade.....	6-33
6.19 Polymer/Chemical Grade Propylene Consumption in Middle East	6-34
6.20 Refinery Grade Propylene Consumption in Middle East	6-35
6.21 Polymer/Chemical Grade Propylene Capacity Middle East.....	6-36
6.22 Propylene Supply, Demand, and Trade in Middle East.....	6-37
6.23 Propylene Consumption in ROW	6-38
6.24 Polymer Grade Propylene Capacity in ROW	6-40
6.25 Polymer Grade Propylene Capacity in ROW	6-41
6.26 Chemical Grade Propylene Capacity in ROW.....	6-42
6.27 ROW Supply, Demand, and Trade	6-42